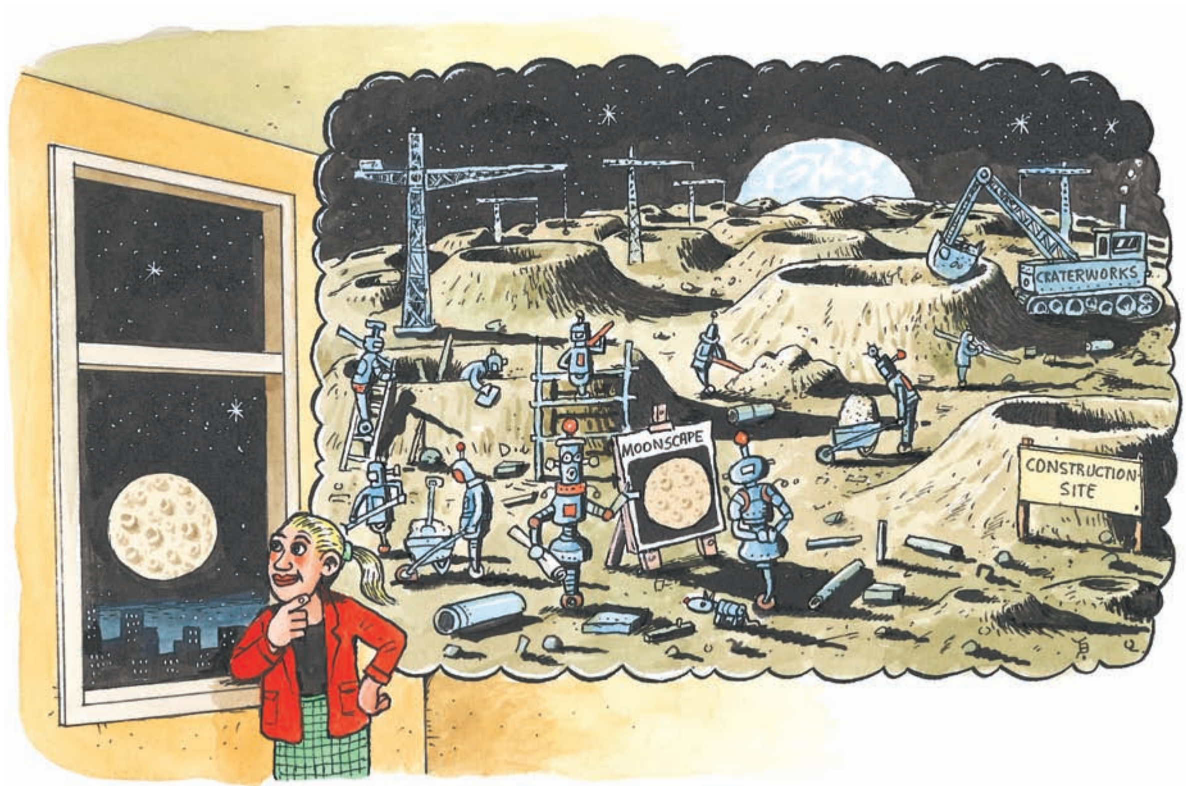
Activity 2 The Earth–Moon System



Goals

In this activity you will:

- Investigate lunar phases using a model and observations in your community.
- Investigate the general idea of tidal forces.
- Understand the role of the Earth, the Moon, and the Sun in creating tides on Earth.
- Understand the Earth–Moon system and the Moon's likely origin.
- Compare the appearance of the Moon to other solar-system bodies.

Think about It

Think about the last time that you gazed at a full Moon.

- What happened to make the Moon look the way it does?
- What is the origin of the Moon?
- How does the Moon affect the Earth?

What do you think? Record your ideas about these questions in your *EarthComm* notebook. Be prepared to discuss your responses with your small group and the class.

Investigate

Part A: Lunar Phases

1. Attach a pencil to a white Styrofoam® ball (at least 5 cm in diameter) by pushing the pencil into the foam. Set up a light source on one side of the room. Use a lamp with a bright bulb (150-W) without a lampshade or have a partner hold a flashlight pointed in your direction. Close the shades and turn off the overhead lights.
2. Stand approximately 2 m in front of the light source. Hold the pencil and ball at arm's length away with your arm extended towards the light source. The ball represents the Moon. The light source is the Sun. You are standing in the place of Earth.
   a) How much of the illuminated Moon surface is visible from Earth? Draw a sketch of you, the light source, and the foam ball to explain this.
3. Keeping the ball straight in front of you, turn 45° to your left but stay standing in one place.
   a) How much of the illuminated Moon surface is visible from Earth?
   b) Has the amount of light illuminating the Moon changed?
   c) Which side of the Moon is illuminated? Which side of the Moon is still dark? Draw another diagram in your notebook of the foam ball, you, and the light source in order to explain what you see.
4. Continue rotating counterclockwise away from the light source while holding the ball directly in front of you. Observe how the illuminated portion of the Moon changes shape as you turn 45° each time.
   a) After you pass the full Moon phase, which side of the Moon is illuminated? Which side of the Moon is dark?
   b) How would the Moon phases appear from Earth if the Moon rotated in the opposite direction?

Be careful not to poke the sharp end of the pencil into your skin while pushing the pencil into the foam. Use caution around the light source. It is hot. Do not touch the Styrofoam to the light.

Part B: Observing the Moon

1. Observe the Moon for a period of at least four weeks. During this time you will notice that the apparent shape of the Moon changes.
   a) Construct a calendar chart to record what you see and when you see it. Sketch the Moon, along with any obvious surface features that you can see with the naked eye or binoculars.
   b) Do you always see the Moon in the night sky?
   c) How many days does it take to go through a cycle of changes?
   d) What kinds of surface features do you see on the Moon?
   e) Label each phase of the Moon correctly and explain briefly the positions of the Sun, the Earth, and the Moon during each phase.

Tell an adult before you go outside to observe the Moon.

Part C: Tides and Lunar Phases

1. Investigate the relationship between tides and phases of the Moon.
   a) On a sheet of graph paper, plot the high tides for each city and each day in January shown in *Table 1*. To prepare the graph, look at the data to find the range of values. This will help you plan the scales for the vertical axis (tide height) and horizontal axis (date).
   b) On the same graph, plot the Moon phase using a bold line. Moon phases were assigned values that range from zero (new Moon) to four (full Moon).
2. Repeat this process for low tides.
3. Answer the following questions in your *EarthComm* notebook:
   a) What relationships exist between high tides and phases of the Moon?
   b) What relationships exist between low tides and phases of the Moon?
   c) Summarize your ideas about how the Moon affects the tides. Record your ideas in your *EarthComm* notebook.

Table 1 Heights of High and Low Tides in Five Coastal Locations during January 2001
(All heights are in feet.)

			Breakwater, Delaware		Savannah, Georgia		Portland, Maine		Cape Hatteras, North Carolina		New London, Connecticut	
Date	**Moon Phase**	**Moon Phase**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
1/3/01	First Quarter	2	3.6	0.2	7.3	0.5	8.5	1	2.6	0.2	2.4	0.3
1/6/01	Waxing Gibbous	3	4.5	0	8.2	0.5	9.7	0.1	3.4	–0.4	3	–0.2
1/10/01	Full Moon	4	5.6	–0.9	9.4	–1.5	11.6	–1.9	4.2	–0.8	3.5	–0.7
1/13/01	Waning Gibbous	3	5.1	–0.7	8.8	–0.9	11	–1.4	3.7	–0.6	3	–0.5
1/16/01	Last Quarter	2	4.1	–0.1	7.9	–0.2	9.7	0.1	3	–0.2	2.7	0
1/20/01	Waning Crescent	1	4.3	0.1	7.3	0.2	9.4	0.2	3.2	0	2.8	0
1/24/01	New Moon	0	4.6	0	8.1	–0.1	9.7	–0.1	3.3	–0.1	2.8	–0.1
1/30/01	Waxing Crescent	1	3.7	0.1	7.4	0.1	8.7	0.6	2.6	0	2.4	0.2

4. *Table 1* shows data from the month of January 2001. At the *EarthComm* web site, you can obtain tidal data during the same period that you are doing your Moon observations. Select several cities nearest your community.
   a) Record the highest high tide and the lowest low tide data for each city. Choose at least eight different days to compare. Correlate these records to the appearance of the Moon during your observation period. Make a table like *Table 1* showing high and low tides for each location.
   b) What do you notice about the correlation between high and low tides and the appearance of the Moon?

Part D: Tidal Forces and the Earth System

1. Use the data in *Table 2*.
   a) Plot this data on graph paper. Label the vertical axis "Number of Days in a Year" and the horizontal axis "Years before Present." Give your graph a title.
   b) Calculate the rate of decrease in the number of days per 100 million years (that is, calculate the slope of the line).
2. Answer the following questions:
   a) How many fewer days are there every 10 million years? every million years?
   b) Calculate the rate of decrease per year.
   c) Do you think that changes in the number of days in a year reflect changes in the time it takes the Earth to orbit the Sun, or changes in the time it takes the Earth to rotate on its axis? In other words, is a year getting shorter, or are days getting longer? How would you test your idea?

Table 2 Change in Rotation of Earth Due to Tidal Forces

Period	Date (millions of years ago)	Length of Year (days)
Precambrian	600	424
Cambrian	500	412
Ordovician	425	404
Silurian	405	402
Devonian	345	396
Mississippian	310	393
Pennsylvanian	280	390
Permian	230	385
Triassic	180	381
Jurassic	135	377
Cretaceous	65	371
Present	0	365.25

Reflecting on the Activity and the Challenge

In this activity you used a simple model and observations of the Moon to explore lunar phases and surface characteristics of the Moon. You also explored the relationship between tides and the phases of the Moon. The tides also have an effect that decreases the number of days in a year over time. That's because tides slow the rotation of the Earth, making each day longer. You now understand that tides slow the rotation of the Earth, and how this has affected the Earth. This will be useful when describing the Earth's gravitational relationships with the Moon for the **Chapter Challenge.**

Geo Words

accretion: the process whereby dust and gas accumulated into larger bodies like stars and planets.

Digging Deeper

THE EVOLUTION OF THE EARTH–MOON SYSTEM

The Formation of the Earth and Moon

Figure 1 The Moon is the only natural satellite of Earth.

You learned in the previous activity that during the formation of the solar system, small fragments of rocky material called planetesimals stuck together in a process called **accretion**. Larger and larger pieces then came together to form the terrestrial planets. The leftovers became the raw materials for the asteroids and comets. Eventually, much of this material was "swept up" by the newborn inner planets. Collisions between the planets and the leftover planetesimals were common. This was how the Earth was born and lived its early life, but how was the Moon formed?

Scientists theorize that an object the size of Mars collided with and probably shattered the early Earth. The remnants of this titanic collision formed a ring of debris around what was left of our planet. Eventually this material accreted into a giant satellite, which became the Moon. Creating an Earth–Moon system from such a collision is not easy. In computer simulations, the Moon sometimes gets thrown off as a separate planet or collides with the Earth and is destroyed. However, scientists have created accurate models that predict the orbit and composition of both the Earth and Moon from a collision with a Mars-sized object. The Moon's orbit (its distance from the Earth, and its speed of movement) became adjusted so that the gravitational pull of the Earth is just offset by the centrifugal force that tends to make the Moon move off in a straight line rather than circle the Earth. After the Earth–Moon system became stabilized, incoming planetesimals continued to bombard the two bodies, causing impact craters. The Earth's surface has evolved since then. Because the Earth is geologically an active place, very few craters remain. The Moon, however, is geologically inactive. *Figure 2* shows the Moon's pockmarked face that has preserved its early history of collisions.

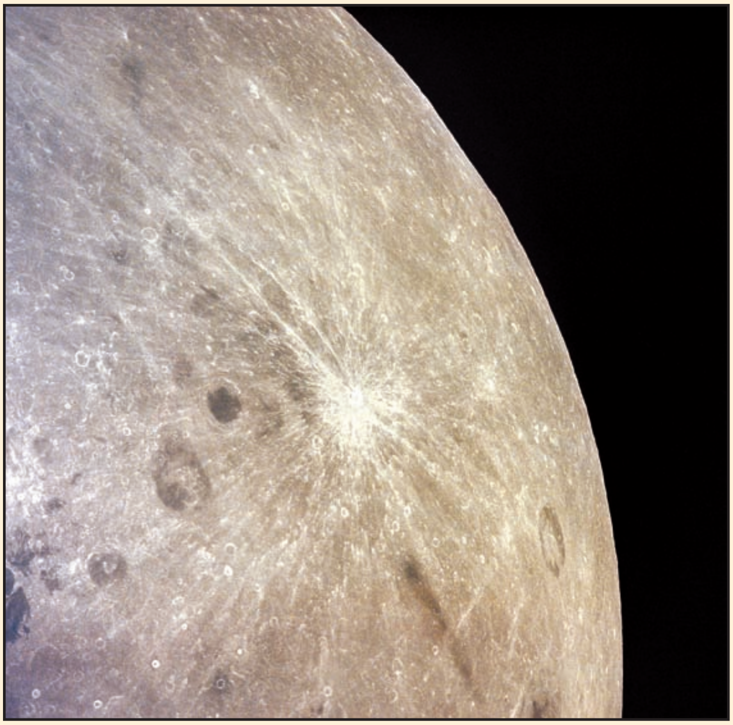


Figure 2 Impact craters on the Moon.

When the Earth was first formed, its day probably lasted only about six hours. Over time, Earth days have been getting longer and longer. In other words, the Earth takes longer to make one full rotation on its axis. On the other hand, scientists have no reason to think that the time it takes for the Earth to make one complete revolution around the Sun has changed through geologic time. The result is that there are fewer and fewer days in a year, as you saw in the **Investigate** section. Why is the Earth's rotation slowing down? It has to do with the gravitational forces between the Earth, the Moon, and the Sun, which create ocean tides.

Tides

The gravitational pull between the Earth and the Moon is strong. This force actually stretches the solid Earth about 20 cm along the Earth–Moon line. This stretching is called the Earth tide. The water in the oceans is stretched in the same way. The stretching effect in the oceans is greater than in the solid Earth, because water flows more easily than the rock in the Earth's interior. These bulges in the oceans, called the ocean tide, are what create the high and low tides (see *Figure 3*). It probably will seem strange

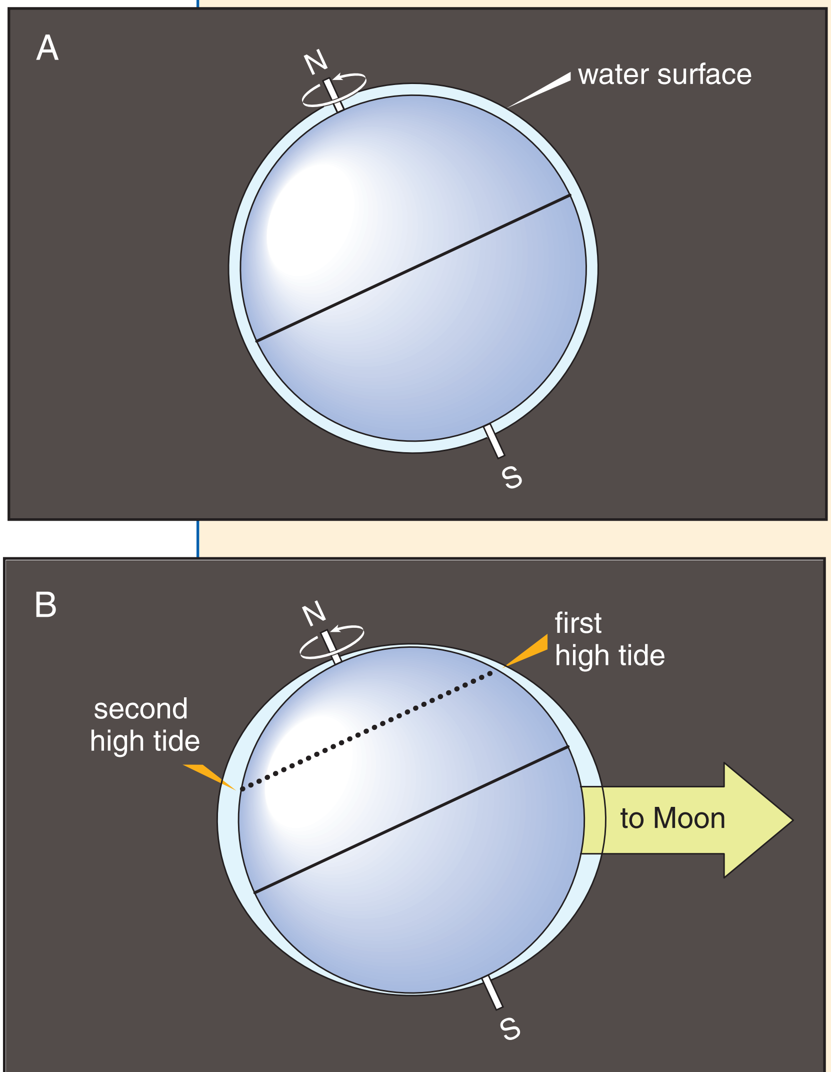


Figure 3 Schematic diagram of tides. Diagram A illustrates how the ocean surface would behave without the Moon and the Sun (no tides). Diagram B illustrates, that in the presence of the Moon and the Sun, shorelines away from the poles experience two high tides and two low tides per day.

to you that there are two bulges, one pointing toward the Moon and the other away from the Moon. If the tides are caused by the pull of the Moon, why is there not just one bulge pointing toward the Moon? The explanation is not simple. If you are curious, you can pursue it further in the **Inquiring Further** section of this activity.

As the Earth rotates through a 24-h day, shorelines experience two high tides—one when the tidal bulge that points toward the Moon passes by, and once when the tidal bulge that points away from the Moon passes by. The tidal cycle is not exactly 24 h. By the time the Earth has completed one rotation (in 24 h), the Moon is in a slightly different place because it has traveled along about 1/30 of the way in its orbit around the Earth in that 24-h period. That's why the Moon rises and sets about 50 min. later each day, and why high and low tides are about 50 min. later each day. Because there are two high tides each day, each high tide is about 25 min. later than the previous one.

The gravitational pull of the Sun also affects tides. Even though it has much greater mass than the Moon, its tidal effect is not as great, because it is so much farther away from the Earth. The Moon is only 386,400 km away from the Earth, whereas the Sun is nearly 150,000,000 km away. The Moon exerts 2.4 times more tide-producing force on the Earth than the Sun does. The changing relative positions of the Sun, the Moon, and the Earth cause variations in high and low tides.

The lunar phase that occurs when the Sun and the Moon are both on the same side of the Earth is called the new Moon. At a new Moon, the Moon is in the same direction as the Sun and the Sun and Moon rise together in the sky. The tidal pull of the Sun and the Moon are adding together, and high tides are even higher than usual, and low tides are even lower than usual. These tides are called **spring tides** (see *Figure 4*). Don't be confused by this use of the word "spring." The spring tides have nothing to do with the spring season of the year! Spring tides happen when the Sun and Moon are in general alignment and raising larger tides. This also happens at another lunar phase: the full Moon. At full Moon, the Moon and Sun are on opposite sides of the Earth. When the Sun is setting, the full Moon is rising. When the Sun is rising, the full Moon is setting. Spring tides also occur during a full Moon, when the Sun and the Moon are on opposite sides of the Earth. Therefore, spring tides occur twice a month at both the new-Moon and full-Moon phases.

Geo Words

spring tide: the tides of increased range occurring semimonthly near the times of full Moon and new Moon.

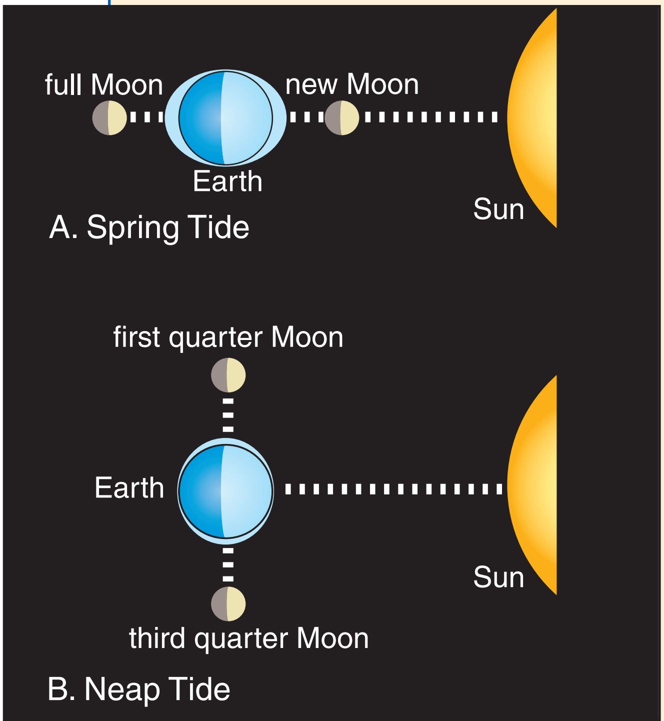


Figure 4 Schematic diagrams illustrating spring and neap tides.

When the line between the Earth and Sun makes a right angle with the line from the Earth to the Moon, as shown in *Figure 4*, their tidal effects tend to counteract one another. At those times, high tides are lower than usual and low tides are higher than usual. These tides are called **neap tides**. They occur during first quarter and third-quarter Moons. As with spring tides, neap tides occur twice a month.

The tide is like a kind of ocean wave. The high and low tides travel around the Earth once every tidal cycle, that is, twice per day. This wave lags behind the Earth's rotation, because it is forced by the Moon to travel faster than it would if it were free to move on its own. That's why the time of high tide generally does not coincide with the time that the Moon is directly overhead. The friction of this lag gradually slows the Earth's rotation.

Another way to look at tides is that the tidal bulges are always located on the sides of the Earth that point toward and away from the Moon, while the Earth with its landmasses is rotating below the bulges. Each time land on the spinning Earth encounters a tidal bulge there is a high tide at that location. The mass of water in the tidal bulge acts a little like a giant brake shoe encircling the Earth. Each time the bulge of water hits a landmass, energy is lost by friction. The water heats up slightly. (This is in addition to the energy lost by waves hitting the shore, which also heats the water by a small fraction of a degree.) Over long periods of time, the tidal bulge has the effect of slowing down the rotation of the Earth, and actually causing the Moon to move away from the Earth. The current rate of motion of the Moon away from the Earth is a few centimeters a year. This has been established by bouncing laser beams off of reflectors on the Moon to measure its distance. Although the Moon's orbit is not circular and is complex in its shape, measurements over many years have established that the

Geo Words

neap tide: the tides of decreased range occurring semimonthly near the times of the first and last quarter of the Moon.

Moon is indeed moving away from the Earth. Special super-accurate clocks have also established that the day is gradually becoming slightly longer as well, because of this same phenomenon, called "tidal friction." The day (one rotation of the Earth on its axis) has gradually become longer over geologic time. As the Earth system evolves, cycles change as well.

In this activity you limited the factors that cause and control the tides to the astronomical forces. These factors play only one part. The continents and their different shapes and ocean basins also play a large role in shaping the nature of the tides. Although many places on Earth have two high tides and two low tides every day (a semidiurnal tide), some places experience only one high tide and one low tide every day (a diurnal tide). There are still other places that have some combination of diurnal and semidiurnal tides (mixed tides). In these places (like along the west coast of the United States) there are two high tides and two low tides per day, but the heights of the successive highs and lows are considerably different from one another.

Figure 5 How do tides affect coastal communities?

Check Your Understanding

1. How did the Moon likely form?
2. Describe the relative positions of the Earth, the Moon, and the Sun for a spring tide and for a neap tide.
3. What effect have tides had on the length of a day? Explain.

Understanding and Applying What You Have Learned

1. Refer back to the graph of the changing length of the day that you produced in the investigation. Think about the causes of tidal friction and the eventual outcome of tidal friction. Predict how long you think the day will eventually be. Explain the reasoning for your prediction.

2. Think about the roles that the Sun and Moon play in causing the ocean tides.

   a) If the Earth had no Moon, how would ocean tides be different? Explain your answer.
   b) How would the ocean tides be different if the Moon were twice as close to the Earth as it is now?
   c) What differences would there be in the ocean tides if the Moon orbited the Earth half as fast as it does now?

3. Look at *Figure 3B* in in the **Digging Deeper** section. Pretend that you are standing on a shoreline at the position of the dotted line. You stand there for 24 h and 50 min, observing the tides as they go up and down.

   a) What differences would do you notice, if any, between the two high tides that day?
   b) Redraw the diagram from *Figure 3B*, only this time, make the arrow to the Moon parallel to the Equator. Make sure you adjust the tidal bulge to reflect this new position of the Moon relative to the Earth. What differences would you now see between the two high tides that day (assuming that you are still at the same place)?
   c) Every month, the Moon goes through a cycle in which its orbit migrates from being directly overhead south of the Equator to being directly overhead north of the Equator and back again. To complicate things, the maximum latitude at which the Moon is directly overhead varies between about 28.5° north and south, to about 18.5° north and south (this variation is on a 16.8 year cycle). How do you think the monthly cycle relates to the relative heights of successive high tides (or successive low tides)?

4. Return to the tide tables for the ocean shoreline that is nearest to your community (your teacher may provide a copy of these to you).

   a) When is the next high tide going to occur? Find a calendar to determine the phase of the Moon. Figure out how to combine these two pieces of information to determine whether this next high tide is the bulge toward the Moon or away from the Moon.
   b) The tide tables also provide the predicted height of the tides. Look down the table to see how much variation there is in the tide heights. Recalling that the Sun also exerts tidal force on the ocean water, try to draw a picture of the positions of the Earth, Moon, and Sun for:
      i) The highest high tide you see on the tidal chart.
      ii) The lowest high tide you see on the tidal chart.
      iii) The lowest low tide you see on the tidal chart.

5. The questions below refer to your investigation of lunar phases.

   a) Explain why the Moon looks different in the sky during different times of the month.

b) What advantage is there to knowing the phases of the Moon? Who benefits from this knowledge?

c) It takes 27.32166 days for the Moon to complete one orbit around the Earth. The Moon also takes 27.32166 days to complete the rotation about its axis. How does this explain why we see the same face of the Moon all the time?

Preparing for the Chapter Challenge

Write several paragraphs explaining the evolution of the Earth–Moon system, how mutual gravitational attraction can affect a community through the tides, and how the changing length of the day could someday affect the Earth system. Be sure to support your positions with evidence.

Inquiring Further

1. **Tidal bulge**

   Use your school library or the library of a nearby college or university, or the Internet, to investigate the reason why the tidal bulge extends in the direction away from the Moon as well as in the direction toward the Moon. Why does the Earth have two tidal bulges instead of just one, on the side closest to the Moon?

2. **Tidal forces throughout the solar system**

   Tidal forces are at work throughout the solar system. Investigate how Jupiter's tidal forces affect Jupiter's Moons Europa, Io, Ganymede, and Callisto. Are tidal forces involved with Saturn's rings? Write a short report explaining how tidal friction is affecting these solar-system bodies.

3. **Impact craters**

   Search for examples of impact craters throughout the solar system. Do all the objects in the solar system show evidence of impacts: the planets, the moons, and the asteroids? Are there any impact craters on the Earth, besides the Meteor Crater in Arizona?